BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Determination of SM RCS Propellant Requirements for AAP and Apollo Rendezvous - Case 610

DATE: July 26, 1968

FROM: K. E. Martersteck

ABSTRACT

From discussions with MSC mission planning personnel, it appears that the RCS propellant budgeting for rendezvous terminal phase is a matter of engineering judgment based on interpretation of Gemini results and simulation data. Present AAP rendezvous budgets do not appear to be unreasonable in comparison with Apollo, particularly when the importance of the AAP rendezvous to mission success is considered.

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MEMORANDUM FOR FILE

In an effort to shed further light on the differences between the Apollo "C" and AAP mission RCS propellant budgets for rendezvous (Reference 1), D. A. De Graaf and the author met at MSC on July 10 with E. D. Murrah, G. L. Hunt, Mrs. C. T. Osgood, S. P. Condon, and K. A. Young of the Mission Planning and Analysis Division (MPAD) and H. E. Whitacre of the MSC Apollo Applications Program Office and on July 11 with R. H. Brown and D. A. Nelson of MPAD.

It became clear during the discussions that rendezvous propellant budgeting is not an exact science. Generally speaking, it is a question of judgment on the part of the budget maker as to how the Gemini flight experience and Apollo man-in-the-loop simulation results should be applied to a given plan for future flight. Unfortunately, the number of actual Gemini rendezvous were too few to generate good statistical data and valid simulation data is apparently not much more plentiful.

Experience indicates that the terminal phase initiation (TPI) burn required is usually close to the theoretical value. The major budget issue therefore becomes the propellant required for mid-course corrections, attitude control during terminal phase, maneuvers normal to line of sight and final braking. Each person in the business seems to have some "rule of thumb" to make this determination. For example, based on his analysis of Gemini results and the simulations, Don Nelson, who does the RCS budgeting for Apollo, says for a "nominal" rendezvous, post-TPI requirements equal about 2.5 times the TPI requirement; "worst case" requirements will probably be as high as six times TPI. Others prefer to use a multiplicative factor plus a constant additive term. Most of these approaches seem to result in similar propellant consumption predictions but they cannot be compared meaningfully by using statistical statements such as "this one is a mean value" or "that one is a mean plus one sigma", etc.

With respect to the comparison between Apollo "C" and the AAP CM/SM rendezvous, it was pointed out that there are differences in the trajectory geometry:

	Apollo "C"	AAP-1
Δh	7.64 nm	9.83 nm
ωt	140.7°	130°
Δv: TPI	16.8 fps	21.6 fps
TPF	17.3 fps	26.6 fps
TOTAL	34.1 fps	48.2 fps

Although analyses indicated Δh = 10 nm to be optimum for controlling coelliptic rendezvous, the Apollo "C" Δh was reduced to ensure that the S-IVB would be visible (at the time this mission was planned, no lights were carried on the S-IVB stage). Apollo "C" has been planned for the 140° transfer angle used in Gemini. Subsequent analysis has shown that a 130° transfer angle produces better LOS rates, i.e., an LOS rate near zero for a longer period near TPF. Thus, while the theoretical Δv for the AAP rendezvous is higher than Apollo, dispersions should be less since the AAP rendezvous parameters Δh and ωt are planned for optimum values according to current analyses and simulations.

The Apollo "C" rendezvous terminal phase RCS budget total as detailed in Reference 2 is very close to what one would predict using Don Nelson's "rule of thumb" mentioned above. A similar calculation for the AAP-1 case yields a requirement for 336 lbs of RCS propellant compared with 435 lbs currently budgeted. This "extra" 100 lbs plus a quantity 1σ = 88 lbs RSS'd with 1σ values for the other maneuvers is included to correct possible trajectory and/or systems dispersions. The Apollo "C" budget has no specific provisions for dispersions. About 60 lbs of propellant are available but not budgeted for any particular maneuvers. It was emphasized several times that the rendezvous is a much less significant part of the Apollo "C" mission than of the AAP mission. On the Apollo mission a flight control RCS redline will be established as a mission rule. If the propellant consumption during the rendezvous exceeds the redline value, the rendezvous will be terminated. On the AAP missions, of course, rendezvous failure precludes mission success. Therefore, AAP must provide for more dispersed cases. The extent to which this is done is a matter of judgment on the part of the mission planners.

Perhaps a better comparison with the AAP rendezvous requirements may be made by considering a version of Apollo "D" mission in which the CM/SM and LM, having been launched together into earth orbit on AS503, separate and fly some distance apart. Rendezvous is then accomplished with the CM/SM rather than the LM as the active vehicle. Reference 3 contains an estimate of the SM RCS propellant requirements for such a mission. For the rendezvous portion of the budget, data was taken directly from Reference 4 and is quoted below:

TPI Maneuver	21 fps	84 lbs
Impulsive TPF Maneuver	24 fps	96 lbs
Post TPI Attitude Control	---	85 lbs
Penalty for 1σ Velocity Errors	56 fps	224 lbs
1σ TOTAL		489 lbs
Additional penalty for 3σ Velocity Errors	80 fps	320 lbs
3σ TOTAL		809 lbs

It should be noted that the "1σ Total" appears to be comparable to the AAP budgeted value of 435 lbs when the appropriate Δv-to-propellant calculation is made for AAP.

In summary, rendezvous propellant budgeting appears to be largely a question of analysis tempered by engineering judgment as to how Gemini and simulation results should be applied to a given situation. Present AAP rendezvous budgets do not appear to be unreasonable when the importance of the rendezvous to mission success is considered. Further refinements must await extensive new simulations and early Apollo mission results.

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K. E. Martersteck

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References

1. Discussion of Differences in RCS Propellant Budgets between Apollo "C" Mission and AAP Missions 1, 3A and 3, Memorandum for File by K. E. Martersteck, May 22, 1968.

2. Apollo Mission C (AS-205/CSM-101) Spacecraft Reference Trajectory Volume IV - Consummables Analysis, MSC Internal Note No. 68-FM-96.

3. MSC Memorandum 68-FM74-75, Subj: Estimates of SM-RCS and LM-RCS Propellant Requirements for a Mission "D" Profile which Includes a Docked APS Burn and a CSM Active Rendezvous, dated February 13, 1968.

4. Apollo Rendezvous with Command Module Active, MSC Internal Note No. 76-EG-23, dated September 28, 1967.

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